U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB-281 043

Emissions from the Crushed Granite Industry State-of-the-Art

Monsanto Research Corp, Dayton, Ohio

Prepared for

Industrial Environmental Research Lab -Cincinnati, Ohio

Feb 78

PB 281 043

EPA-600/2-78-021
February 1978

Environmental Protection Technology Series

EMISSIONS FROM THE CRUSHED GRANITE INDUSTRY: State of the Art

Industrial Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/2-78-021		

4. TITLE AND SUBTITLE	5. REPORT DATE
EMISSIONS FROM THE CRUSHED GRANITE INDUSTRY State of the Art	February 1978 issuing date
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) P. K. Chalekode, J. A. Peters, T. R. Blackwood, and S. R. Archer	8. PERFORMING ORGANIZATION REPORT NO. MRC-DA-706
9. PERFORMING ORGANIZATION NAME AND ADDRESS Monsanto Research Corporation 1515 Nicholas Road Dayton, Ohio 45407	10. PROGRAM ELEMENT NO. 1BB610 11. CONTRACT/GRANT NO. 68-02-1874
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Laboratory-Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268	13. TYPE OF REPORT AND PERIOD COVERED Task Final, 4/75 - 7/77 14. SPONSORING AGENCY CODE EPA/600/12

15. SUPPLEMENTARY NOTES

IERL-Ci project leader for this report is Roger C. Wilmoth, 513-684-4417

16. ABSTRACT

This report describes a study of atmospheric emissions from the crushed granite industry. The potential environmental effect of this emission source was evaluated using source severity, defined as the ratio of the maximum time-averaged ground level concentration of a pollutant at a representative plant boundary to a hazard factor. The hazard factor is the ambient air quality standard for criteria pollutants and an adjusted threshold limit value for noncriteria pollutants. Pollutants are emitted from several operations including drilling, blasting, transport on unpaved roads, crushing, screening, conveying, and stockpiling. Emission factors are determined for particulates emitted from trace operations. The emission rate of respirable particulates (<7 μm) is 6.9 kg/hr. The major hazardous constituent in the dust is free silica (27.2% by weight).

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air pollution Carbon monoxide Dust Silicon dioxide Granite Nitrogen oxides	Air pollution control Stationary sources Source severity Particulate	50 B

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Unlimited	Unclassified	68
	20. SECURITY CLASS (This page) Unclassified	22. PRICE PC A04/MF A01

EPA Form 2220-1 (9-73)

* U.S. GOVERNMENT PRINTING OFFICE: 1978— 720-335/6083

EPA-600/2-78-021
February 1978

EMISSIONS FROM THE CRUSHED GRANITE INDUSTRY
State of the Art

by

P. K. Chalekode, J. A. Peters, T. R. Blackwood, and S. R. Archer
Monsanto Research Corporation
Dayton, Ohio 45407

Contract No. 68-02-1874

Project Officer

Roger C. Wilmoth
Resource Extraction and Handling Division
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory-Cincinnati, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report contains an assessment of air emissions from the crushed granite industry. This study was conducted to provide a better understanding of the distribution and characteristics of emissions from crushed granite operations. Further information on this subject may be obtained from the Extraction Technology Branch, Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

PREFACE

The Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) has the responsibility for insuring that pollution control technology is available for stationary sources to meet the requirements of the Clean Air Act, the Federal Water Pollution Control Act, and solid waste legislation. If control technology is unavailable, inadequate, uneconomical, or socially unacceptable, then financial support is provided for the development of the needed control techniques for industrial and extractive process industries. Approaches considered include: process modifications, feedstock modifications, add-on control devices, and complete process substitution. The scale of the control technology programs ranges from bench- to full-scale demonstration plants.

IERL has the responsibility for developing control technology for a large number (>500) of operations in the chemical and related industries. As in any technical program, the first step is to identify the unsolved problems. Each of the industries is to be examined in detail to determine if there is sufficient potential environmental risk to justify the development of control technology by IERL.

Monsanto Research Corporation (MRC) has contracted with EPA to investigate the environmental impact of various industries that represent sources of pollutants in accordance with EPA's responsibility, as outlined above. Dr. Robert C. Binning serves as MRC Program Manager in this overall program, entitled "Source Assessment," which includes the investigation of sources in each of four categories: combustion, organic materials, inorganic materials, and open sources. Dr. Dale A. Denny of the Industrial Processes Division at Research Triangle Park serves as EPA Project Officer for this series. Reports prepared in this program are of two types: Source Assessment Documents, and State-of-the-Art Reports.

Source Assessment Documents contain data on pollutants from specific industries. Such data are gathered from the literature, government agencies, and cooperating companies. Sampling and analysis are also performed by the contractor when the available information does not adequately characterize the source pollutants. These documents contain all of the information necessary for IERL to decide whether a need exists to develop additional control technology for specific industries.

State-of-the-Art Reports include data on pollutants from specific industries which are also gathered from the literature, government agencies, and cooperating companies. No extensive sampling, however, is conducted by the contractor for such industries. Sources in this category are considered by EPA to be of insufficient priority to warrant complete assessment for control technology decisionmaking. Therefore, results from such studies are published as State-of-the-Art Reports for potential utility by the government, industry, and others having specific needs and interests.

This State-of-the-Art Report contains data on air emissions from the crushed granite industry. This project was initiated by the Chemical Processes Branch of the Industrial Processes Division at Research Triangle Park; Mr. D. K. Oestreich served as EPA Project Leader. The project was transferred to and completed by the Resource Extraction and Handling Division, IERL-Cincinnati, where Mr. Roger C. Wilmoth served as EPA Task Officer.

ABSTRACT

This report describes a study of air pollutants emitted by the crushed granite industry. The potential environmental effect of the source was evaluated using source severity values (source severity is the ratio of the maximum time-averaged ground level concentration of an emission to its hazard factor).

In 1972, 155 crushed granite processing plants in the U.S. operated 412 quarries and produced 96.5 million metric tons of crushed granite.

A typical crushed granite plant has a production rate of 450 metric tons/hr and emits pollutants from several operations including drilling, blasting, transport on unpaved roads, crushing, screening, conveying, and stockpiling. The emission factor for total particulates emitted from the representative plant is 49 kg/hr; blasting contributes 74% of the overall emissions. The emission rate of respirable particulates is 6.9 kg/hr. The major hazardous constituent in the dust is free silica (27.2% by weight), prolonged exposure to which may result in the development of a pulmonary fibrosis known as silicosis. Nitrogen oxides and carbon monoxide are emitted by the blasting operation, but the emission factors and corresponding source severities are small in comparison to particulate emissions.

The affected population value for an emission is defined as the number of persons living in areas beyond the plant boundary where the source severity is 0.1 or greater. The maximum source severity for total particulates is calculated as 0.99. The population affected value for total particulate emissions from the crushed granite industry is 610 persons. Similarly, the source severity due to free silica in the respirable particulate emissions is 32.7, and the affected population is 31,400 persons. The industry is expected to grow at a rate of 4% per year, and by 1978 its emissions are predicted to increase by 28% over the 1972 level.

This report was submitted in partial fulfillment of Contract No. 68-02-1874 by Monsanto Research Corporation under the sponsorship of the U.S. Environmental Protection Agency. The study covers the period April 1975 to July 1977, and the work was completed in August 1977.

CONTENTS

Foreword iii
Preface iv
Abstract vi
Figures viii
Tables viii
Abbreviations and Symbols ix
Conversion Factors and Metric Prefixes xi

1. Introduction 1
2. Summary 2
3. Source Description 5
    Process description 5
    Factors affecting emissions 6
    Geographical distribution 7
4. Emissions 9
    Selected pollutants 9
    Characteristics 9
    Definition of a representative source 10
    Environmental effects 12
5. Control Technology 16
    State of the art 16
    Future considerations 16
6. Growth and Nature of the Industry 20
    Present technology 20
    Emerging technology 20
    Production trends 20

References 22
Appendices

A. Literature survey 25
B. Sampling - details and results 31
C. Source severity and affected population 47

Glossary 51

FIGURES

Number		Page
1	State and nationwide emission burden due to total particulate emissions from crushed granite operations	4
2	Crushed granite operation	5
3	Emission rate of total particulate from crushed granite operations	8

TABLES

1	Mass Emissions from Various Operations in the Crushed Granite Industry	3
2	Crushed Granite Sold or Used by Producers in the United States in 1972, by State	8
3	State and Nationwide Particulate Emissions Burden from Crushed Granite Industry	11
4	Pollutant Source Severity Equations	14
5	Source Severity and Affected Population for Emissions from the Crushed Granite Industry . .	14

ABBREVIATIONS AND SYMBOLS

A	-- cross-sectional area of the falling granules, cm^2
B	-- width of conveyor belt, cm
D	-- representative distance from the major source, m
D_T	-- total dose, $g\text{-}s/m^3$
d	-- height of material fall, cm
E	-- emission factor, g/kg
E_D	-- function of five variables that influence dust emissions from drilling operations
F	-- hazard factor, g/m^3
G	-- gravitational acceleration = 980 cm/s^2
h	-- physical stack height
H	-- effective emission height, m
ΔH	-- plume rise
m_1, m_2	-- slopes used in calculating distances to samplers
M	-- belt load, g/cm^2
P	-- production rate of crushed limestone, metric tons/hr
Q	-- emission rate, kg/hr or g/s (Equation 1)
Q_D	-- line source emissions per length of line, g/m
Q_T	-- total release, g
R	-- specific formation of airborne respirable dust, g
S	-- maximum source severity, dimensionless
$S_0, \ldots S_4$	-- high-volume sampler locations
TLV	-- threshold limit value, g/m^3
u	-- 4.5 m/s (approximate U.S. average wind speed)
U_B	-- linear speed of the conveyor belt, cm/s
x_i, y_i	-- Cartesian coordinates used to relate position of the i-th sampler to the source
x	-- downwind distance from source along the dispersion centerline
x_c	-- crosswind distance from the line source, m

y, y_i	-- lateral distance from dispersion centerline to sampler, m
z	-- vertical distance from the x-y plane of the source to the sampler plane
α	-- angle defined for use in calculating sampler positions, radians
θ	-- wind azimuth angle with respect to the y axis, radians
π	-- a constant
$\bar{\rho}_C$	-- material density of coal, g/cm^3
σ	-- overall standard deviation, m
σ_y	-- horizontal standard deviation of plume dispersion, m
σ_z	-- vertical standard deviation of plume dispersion, m
σ_{zI}	-- instantaneous vertical dispersion parameter, m
χ	-- ground level concentration, g/m^3
χ_i	-- ground level concentration at coordinate location $(x_i, y_i, 0)$, g/m^3
χ_{max}	-- maximum ground level concentration, g/m^3
$\bar{\chi}_{max}$	-- maximum time-averaged ground level concentration, g/m^3
ψ	-- dose, $g/s\text{-}m^3$

CONVERSION FACTORS AND METRIC PREFIXES[a]

Conversion factors

To convert from	to	Multiply by
centimeter (cm)	foot	3.281×10^{-2}
centimeter^2 (cm^2)	inch^2	1.550×10^{-1}
centimeter^3 (cm^3)	inch^3	6.102×10^{-2}
kilogram (kg)	pound-mass (lb mass avoirdupois)	2.204
kilogram (kg)	ton (short, 2,000 lb mass)	1.102×10^{-3}
kilometer^2 (km^2)	mile^2	3.860×10^{-1}
meter (m)	foot	3.281
meter^2 (m^2)	foot^2	1.076×10^{1}
meter^3 (m^3)	foot^3	3.531×10^{1}
meter^3 (m^3)	gallon (U.S. liquid)	2.642×10^{2}
meter^3 (m^3)	liter	1.000×10^{-3}
metric ton	pound-mass	2.205×10^{3}
radian (rad)	degree (°)	5.730×10^{1}

Metric prefixes

Prefix	Symbol	Multiplication factor	Example
kilo	k	10^3	1 kg = 1×10^3 grams
centi	c	10^{-2}	1 cm = 1×10^{-2} meter
milli	m	10^{-3}	1 mm = 1×10^{-3} meter
micro	μ	10^{-6}	1 μm = 1×10^{-6} meter

[a] Metric Practice Guide. ASTM Designation E 380-74, American Society for Testing and Materials. Philadelphia, Pennsylvania, November 1974. 34 pp.

SECTION 1

INTRODUCTION

The conversion of naturally occurring granite to its crushed form involves mining from open quarries and processing at finishing plants. Air pollution problems are attendant to the mining and the processing operations.

An investigation of crushed granite operations was conducted to provide a better understanding of the distribution and characteristics of emissions than had been previously available in the literature. Data collection was designed to document the need for developing control technology in this industry.

This report contains information on the following items:

- A method to estimate the emissions due to crushed granite processing
- Composition of emissions
- Hazard potential of emissions
- Geographical distribution and source severity
- Trends in the crushed granite industry and their effects on emissions
- Type of control technology used and proposed

SECTION 2

SUMMARY

The crushed granite industry converts naturally occurring granite rock deposits into crushed granite for use predominantly (94% of the output) in the construction industry. In 1972, 155 processing plants in the U.S. operating 412 quarries (an average of 2.7 quarries per plant) produced 96.5 million metric tons[a] of crushed granite. Contingency forecasts of crushed granite demands in the year 2000 have been reported to be 332 to 419 million metric tons.

Atmospheric emissions of particulates occur from several unit operations: drilling, blasting, transport on unpaved roads, crushing, screening, conveying, and stockpiling. The emission factor for respirable particulates from crushed granite processing is 1.53×10^{-2} kg/metric ton, with blasting contributing about 88% of the value. The hazardous constituent in the dust is free silica (27.7 wt % average), which may cause the development of silicosis.

A typical crushed granite plant has a production rate of 450 metric tons/hr and emits dust at the rate of 6.9 kg/hr respirable particulate and 49 kg/hr total particulate.

To assess the source severity, the ratio of the maximum ground level concentration at the representative plant boundary to the pollutant hazard factor is used. The hazard factor is defined as the EPA primary air quality standard. When EPA criteria do not exist, an adjusted threshold limit value (TLV®) which allows for exposure time and for the general population is used. The maximum source severity due to free silica emissions (respirable fraction) from a representative plant is 32.7.

Table 1 summarizes the severity and contributions of emissions from the various unit operations. Figure 1 summarizes the contributions of particulate emissions from the crushed granite industry on a state and national basis.

---

[a] 1 metric ton = 10^6 grams; conversion factors and metric system prefixes are presented in the prefatory pages.

TABLE 1. MASS EMISSIONS FROM VARIOUS OPERATIONS IN THE CRUSHED GRANITE INDUSTRY

Unit operation	Emission factor, kg/metric ton	Particulates[a]				Free silica	
		U.S. total kg/yr	Percent of total	Severity for representative plant	Percent respirable	U.S. total kg/yr	Severity for representative plant
Drilling	3.99×10^{-4}	38,500	0.4	3.7×10^{-3}	10.0	1,040	8.5×10^{-2}
Blasting	7.96×10^{-2}	7,681,400	74.4	0.74	16.9	353,000	28.7
Loading onto haul trucks	[b]	[b]	[b]	[b]	[b]	[b]	[b]
Dumping to primary crusher	2.1×10^{-4}	20,300	0.2	1.9×10^{-3}	3.6	200	1.6×10^{-2}
Primary crusher	[b]	[b]	[b]	[b]	[b]	[b]	[b]
Secondary crushing and screening	2.2×10^{-2}	2,123,000	20.6	0.20	3.6	20,800	1.7
Conveying	[b]	[b]	[b]	[b]	[b]	[b]	[b]
Unloading to stockpiles	[b]	[b]	[b]	[b]	[b]	[b]	[b]
Loading from stockpiles	[b]	[b]	[b]	[b]	[b]	[b]	[b]
Vehicular movement on dry unpaved roads	4.91×10^{-3}	473,800	4.6	4.5×10^{-2}	17.6	22,700	1.8
Windblown emissions	[b]	[b]	[b]	[b]	[b]	[b]	[b]
TOTAL[c]	1.07×10^{-1}	10,325,500	100.0	0.99	14.3	402,000	32.7

[a] The values shown are for total particulates.

[b] Negligible.

[c] Data may not add to totals due to independent rounding.

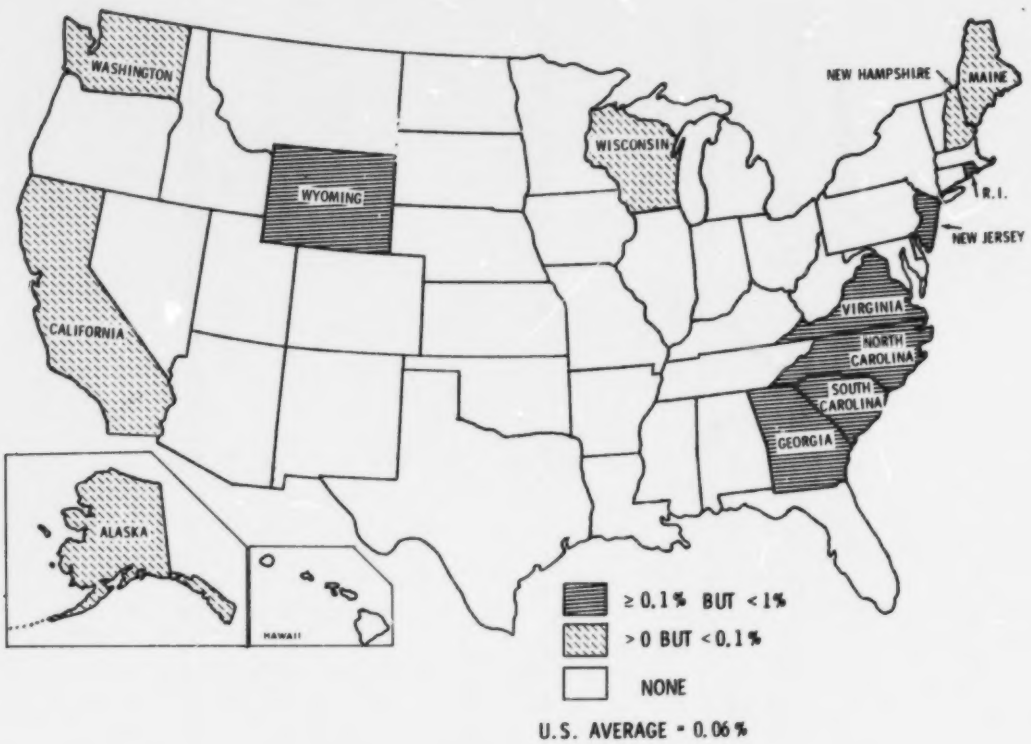

Figure 1. State and nationwide emission burden due to total particulate emissions from crushed granite operations.

Nitrogen oxides and carbon monoxide are emitted by the blasting operation with respective emission factors of 2.85 g/metric ton and 1.68 g/metric ton of material blasted. The maximum source severities due to nitrogen oxides and carbon monoxide are $8.9 \times 8.9 \times 10^{-2}$ and 1.7×10^{-4}, respectively. Similarly, the emission factor of fibers from a representative plant is 3.13×10^{9} fibers/metric ton and the resulting severity is 0.45.

The crushed granite industry is concentrated near granite deposits, adjacent to large, rapidly expanding urban areas, and in areas where large-scale public and private works are under construction. The distribution of plants with respect to the size of localities shows that free silica in the respirable particulate emissions from a representative crushed granite plant affect a population of 31,400 persons to a severity of 0.1. The industry is predicted to grow at the rate of 4% per year, and by 1978 the emissions are estimated to increase 28% from 1972 levels.

SECTION 3

SOURCE DESCRIPTION

PROCESS DESCRIPTION

Emission Sources

The conversion of naturally occurring granite deposits into crushed granite involves a series of physical operations (Figure 2). The deposits are first loosened by drilling and blasting. Granite is then loaded and transported to the processing plant by trucks or belt conveyors. Processing includes such operations as crushing, pulverizing, screening, and conveying. After processing, the granite is loaded for shipment to customers or to stockpiles for storage.

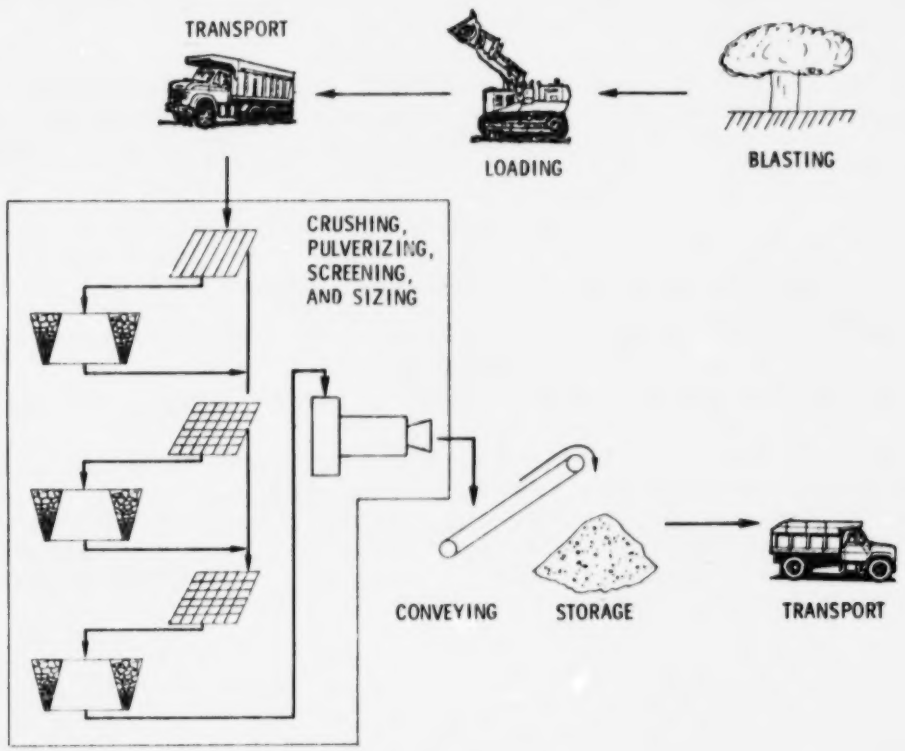

Figure 2. Crushed granite operation.

Fine particulates (<7 μm) emission sources in the crushed granite industry can be divided into two categories: 1) sources associated with actual processing such as crushing, screening, and transfer operations; and 2) fugitive dust sources such as vehicle traffic on unpaved roads, transport operations, and stockpiles. Quarrying operations such as drilling, blasting, fracturing and loading are also fugitive dust sources.

Source Composition

Granite is a plutonic igneous rock with a chemical composition (by weight) of about 72% silica, 13% alumina, 3% ferrous oxide and magnesia, 1% lime, and 9% potash and soda. Its mineralogical composition is ∿43% alkali feldspar, 30% quartz, 10% plagioclase feldspar and 13% ferromagnesia minerals (1).

FACTORS AFFECTING EMISSIONS

Calculation of the source severity and the state and national emissions burdens, necessitates a knowledge of the emission rate for every source in the country. Conducting emission measurements on a source-by-source basis was impractical due to the large number of individual sources and the diversity of source types. A method was therefore developed to derive an emission factor as kilograms of particulates emitted per metric ton of crushed granite processed.

The emission rate for each of the source types is estimated as the product of the emission factor and the crushed granite production rate, expressed as metric tons per hour. This relationship can be stated as:

$$Q = E \times P \qquad (1)$$

where Q = emission rate of particulates, kg/hr

E = emission factor for particulates, kg/metric ton of crushed granite processed

P = production rate of crushed granite, metric ton/hr

The overall emissions from crushed granite operations are due to drilling, blasting, loading, vehicular movement on unpaved roads, crushing, conveying, screening, and stockpiling. Emissions from all of these unit operations (except blasting) are influenced by particle size distribution, rate of handling, moisture content of the handled material, and type of equipment used.

---

(1) Clews, F. H. Heavy Clay Technology, Second Edition. Academic Press, New York, New York, 1969. pp. 1, 4.

A detailed literature survey was conducted to obtain published data on the extent to which various factors influence the overall emissions, and on the relative contributions of the unit operations to overall emissions (see Appendix A). Lack of quantitative data necessitated on-site sampling to develop the emission factor.

Emissions from a crushed granite plant were sampled. (See Appendix B for details and results of the sampling.) The results show that blasting contributes 74% of the total particulate plant emissions. The results also show that the emissions from other unit operations can be reduced if the moisture content is increased.

GEOGRAPHICAL DISTRIBUTION

In the United States, 155 crushed granite processing plants (2) operating 412 quarries (personal communication with W. Pajalich, Bureau of Mines, Washington, D.C., 15 October 1975) had a total output of 96.5 million metric tons in 1972 and 109.1 million metric tons in 1973. Georgia ranked first with 26.9 million metric tons in 1972, followed by North Carolina, Virginia, South Carolina, California, and New Jersey. Together these six states accounted for 82.5% of the toal crushed granite production in the United States (3). Table 2 gives the crushed granite output and the respective population densities for 14 states in the United States. Emission rates for particulates due to crushed granite operations are given in Figure 3.

Geographically, the crushed granite industry is concentrated in large, rapidly expanding urban areas and in areas where large-scale public and private works are under construction.

---

(2) 1972 Census of Mineral Industries, Subject Series; General Summary. MIC 72(1)-1, U.S. Department of Commerce, Washington, D.C., 1975. 174 pp.

(3) Mineral Industry Surveys. U.S. Department of the Interior, Washington, D.C., 1972. 12 pp.

Figure 3. Emission rate of total particulate from crushed granite operations.

TABLE 2. CRUSHED GRANITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1972, BY STATE (3)

State	Amount of granite sold or used, 10^3 metric tons	Population density, persons/km^2
Alaska	28	0.2
California	4,845	50.2
Georgia	26,933	31.4
Maine	89	12.0
New Hampshire	43	32.5
New Jersey	2,302	366.0
North Carolina	23,704	38.8
Pennsylvania	316	102.6
Rhode Island	299	311.8
South Carolina	8,648	33.8
Virginia	12,942	45.6
Washington	1,127	19.6
Wisconsin	1,150	31.5
Wyoming	1,388	1.4
Other states[a]	12,654	
TOTAL[b]	96,468	

[a] Includes Alabama, Arizona, Arkansas, Colorado, Connecticut, Idaho, Maryland, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nevada, New York, Oregon, and Vermont.

[b] Data may not add to totals shown because of independent rounding.

SECTION 4

EMISSIONS

SELECTED POLLUTANTS

The major pollutants emitted from crushed granite processing are dusts containing free silica. The prolonged inhalation of these dusts may result in the development of a disabling pulmonary fibrosis known as silicosis. Silica causes a progressive diffuse, nodular lung fibrosis that may continue to increase for several years after exposure is terminated. The first and most common symptoms of uncomplicated silicosis are dry coughing and shortness of breath on exertion. As the disease advances, the shortness of breath becomes worse and the cough more troublesome. Further progress of the disease results in marked fatigue, loss of appetite, pleuritic pain, and total incapacity to work. Extreme cases may eventually result in death from destruction of the lung tissues (4).

The American Conference of Governmental Industrial Hygienists has suggested a TLV (in mg/m^3) of 10/(% quartz + 2) for respirable dusts containing quartz or free silica. Further, particulate is one of the criteria pollutants. Dusts with less than 1% silica are termed "inert;" a TLV of 10 mg/m^3 has been suggested for them (5).

CHARACTERISTICS

Mass Emissions

The mean emission factor for total particulates is 0.107 kg/metric ton of granite processed through the primary crusher. The mean emission factor for respirable particulates is 0.002 kg/metric ton. Blasting contributes 74% of the overall plant emissions. The foregoing results are based on a sampling of two crushed

---

(4) Sax, N. I. Dangerous Properties of Industrial Materials, Third Edition. Reinhold Book Corporation, New York, New York, 1968. pp. 1088-1089.

(5) TLVs® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1976. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1976. p. 32.

granite plants (see Appendix B for details). The emission factors for nitrogen oxides and carbon monoxide are 2.85 g/metric tons and 1.68 g/metric tons, respectively (6).

The emission factor for total particulates (0.107 kg/metric ton) was used to estimate the statewide emissions from crushed granite processing, as shown in Table 3. Of all the emitted pollutants, particulates are the only criteria pollutant. The state emission burden is calculated as the percent contribution of particulate emission rates for crushed granite processing in a state to the total particulate emission rates in that state. Table 3 displays the total particulate emission by state (7), the 1972 particulate emissions from granite processing by state, and the state and nationwide emission burdens. The emissions of particulates due to crushed granite processing contribute less than 1% to the overall particulate emissions in each state in the U.S.

Composition of Emissions

An analysis of the emissions from crushed granite (Appendix B) shows that free silica, constituting 27.7% by weight, is the only known hazardous component. Other emission constituents (72.3% by weight) are considered inert.

DEFINITION OF A REPRESENTATIVE SOURCE

Consultations with industry experts show that crushed granite plants have an average production rate of 450 metric tons/hr (personal communication with F. Renniger, National Crushed Stone Association, Washington, D.C., 7 November 1975). The mean emission factor was determined by sampling two crushed granite plants believed to be representative of the industry (Appendix B). The representative plant thus emits dust at a rate of 6.9 kg/hr respirable particulates and 48.6 kg/hr total particulates.

The representative population density, the average population density of the six leading crushed granite-producing states of Georgia, North Carolina, Virginia, South Carolina, California, and New Jersey, is equal to 100 persons/km^2. The representative distance from the plant is defined using the major contributing source within the plant as a reference point. The distance of the plant boundaries from this reference point is taken as the radius of a circle whose area is equal to the area of the

---

(6) Blackwood, T. R., P. K. Chalekode, and R. A. Wachter. Source Assessment: Crushed Stone. Contract 68-02-1874, U.S. Environmental Protection Agency, Cincinnati, Ohio, July 1977. 91 pp.

(7) 1972 National Emissions Report. EPA-450/2-74-012, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974. 422 pp.

TABLE 3. STATE AND NATIONWIDE PARTICULATE EMISSIONS BURDEN FROM CRUSHED GRANITE INDUSTRY

State	Total particulate emissions, metric tons/yr (7)	Particulate emissions from granite processing (1972), metric tons/yr	Contributions of crushed granite emissions to overall state emissions, %
Alaska	14,000	3	0.02
California	1,006,000	518	0.05
Georgia	404,000	2,882	0.71
Maine	49,000	10	0.02
New Hampshire	15,000	5	0.03
New Jersey	152,000	246	0.16
North Carolina	481,000	2,536	0.53
Pennsylvania	1,810,000	34	Negl.
Rhode Island	13,000	32	0.24
South Carolina	199,000	925	0.47
Virginia	477,000	1,385	0.29
Washington	162,000	121	0.07
Wisconsin	412,000	123	0.03
Wyoming	75,000	149	0.18
Other states	11,491,000	1,334	0.01
U.S. TOTAL[a]	16,762,000	10,322	0.06

[a]Data may not add to totals shown due to independent rounding.

representative plant. Assuming crushed granite plants have the same average area as crushed stone plants (0.53 km^2), the representative distance to the plant boundaries is 410 m (6).

A representative plant growing at the same rate as the industry will grow at a predicted rate of 4% per year, and by 1978 its emissions will increase by an estimated 28% over 1972 levels.

ENVIRONMENTAL EFFECTS

The source severity indicates the hazard potential of a representative emission source; it is the ratio of the maximum ground level concentration (χ) to a hazard factor (F). A mathematical model describing the dispersion of pollutants in the atmosphere is employed to calculate the source severity, S (which equals χ/F). For open sources, the model uses the concentration of a pollutant occurring at a single point at ground level at the plant boundary. This concentration can occur at one point in time during a year and can thus be considered a worst-case condition. The hazard factor is derived from ambient air quality criteria or reduced threshold limiting values.

Ground Level Concentration

The minimum distance at which public exposure to the pollutant could occur is the distance from the major contributing emission source to the representative crushed granite plant boundary--410 m as shown earlier in this section. The following formula, in conjunction with class C meteorological conditions, was used to calculate the concentration at this distance which is defined as χ_{max}(8) (the maximum ground level instantaneous concentration):

$$\chi_{max} = \frac{Q}{\pi \sigma_y \sigma_z u} \qquad (2)$$

where Q = mass emission rate, g/s

$\sigma_y = 0.209\ x^{0.903}$

$\sigma_z = 0.113\ x^{0.911}$

$u = 4.5$ m/s (approximate U.S. average)

The instantaneous ground level concentration for total particulates at 410 m is thus 736 $\mu g/m^3$. This is corrected to the time

---

(8) Turner, D. B. Workbook of Atmospheric Dispersion Estimates. Public Health Service Publication No. 999-AP-26, U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio, May 1970.

averaged maximum, $\overline{\chi}_{max}$, for 24 hours (9) so that the mean concentration becomes 258 $\mu g/m^3$. This means that over a 24-hr period, the average maximum ground level concentration at the boundary of the representative plant is 258 $\mu g/m^3$ above the background levels.

Hazard Factor

Since no ambient air quality standard exists for free silica, the hazard factor, F, is defined as follows:

$$F = \frac{8}{24} \times \frac{1}{100} \times TLV \qquad (3)$$

The derivation of F utilizes the TLV corrected from 8-hr to 24-hr exposure with a safety factor of 100 applied to the calculation. For the purpose of this report, the free silica hazard factor is calculated as 11.3 $\mu g/m^3$. It should be compared to the respirable emissions, since the TLV used in its definition is for respirable emissions. For total particulates, F shall be defined as the 24-hr ambient air quality standard of 260 $\mu g/m^3$.

Source Severity

For the representative crushed granite plant, the maximum severity is determined from the ratio of the time-averaged maximum ground level concentration of the emission species to the hazard factor for the species ($\overline{\chi}_{max}/F$). The time-averaged maximum ground level concentration is related to the mass emission rate, Q (in g/s), of a pollutant, and for open sources, the representative distance, D, from the source to the plant boundary.

The approach described above leads to the equations in Table 4, which were used to determine the severity of criteria and non-criteria pollutants from the crushed granite industry (10). These equations simplify the calculations of source severity and, ultimately, of the affected population.

---

(9) Nonhebel, G. Recommendations on Heights for New Industrial Chimneys. Journal of the Institute of Fuel, 33:479, 1960.

(10) Blackwood, T. R., and R. A. Wachter. Source Assessment: Coal Storage Piles. Contract 68-02-1874, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, July 1977. 96 pp.

TABLE 4. POLLUTANT SOURCE SEVERITY EQUATIONS

Pollutant	Source severity equation
Particulate	$S = \frac{4{,}020\ Q}{D^{1.81}}$
Nitrogen oxides	$S = \frac{22{,}200\ Q}{D^{1.90}}$
Carbon monoxide	$S = \frac{44.8\ Q}{D^{1.81}}$
Noncriteria pollutant	$S = \frac{316\ Q}{TLV \cdot D^{1.81}}$

where S = source severity
Q = mass emission rate
D = distance from source to plant boundary
TLV = threshold limit value

Table 5 shows the source severities due to, and the population affected by, emissions of criteria and noncriteria pollutants from the crushed granite industry. Severity can also be calculated by taking the ratio χ_{max}/F. Thus, for total particulates (χ_{max} = 258 $\mu g/m^3$ and F = 260 $\mu g/m^3$), the severity is 0.99. Sample calculations for source severity and affected population are provided in Appendix C.

TABLE 5. SOURCE SEVERITY AND AFFECTED POPULATION FOR EMISSIONS FROM THE CRUSHED GRANITE INDUSTRY

Pollutant	Source severity	Affected population,[a] persons
Total particulates	0.99	610
Free silica	32.7	31,400
Nitrogen oxides	0.089	0
Carbon monoxide	1.7×10^{-4}	0
Fibers	0.454	227

[a]Population living beyond the plant boundary where the source severity is 0.1 or greater.

Particulate emissions from the representative plant with a severity of 0.1 affect 610 persons living within 1,450 m from the plant boundary, as computed in Appendix C. The emission rate of free silica in respirable particulates is 14.3% of the total particulate emissions, as shown in Table B-5 (Appendix B). The free silica emissions from the representative plant with a severity of 0.1 affect 31,400 persons living within 10 km from the plant boundary. Severity calculations for nitrogen oxides (NO_x), carbon monoxide (CO), and fiber are provided in Appendix C.

SECTION 5

CONTROL TECHNOLOGY

STATE OF THE ART

Currently there is no designated air pollution control technology or methodology to control emissions from crushed granite operations. Dust generated from the various operations is dependent upon the dryness of the handled material; hence, any method used to add moisture is helpful in controlling dust levels. Natural phenomena such as rain or snow and in-process washing or spraying operations inhibit dust emissions as the dust adhering to water is less prone to be emitted. Some plants apply water to unpaved roads in order to curb emissions due to vehicular movement on the roads, and some employ wet drilling to reduce emissions while drilling blast holes.

FUTURE CONSIDERATIONS

The fugitive and point sources of dust in the processing of granite are drilling, blasting, loading, unpaved road transport, crushing, screening, conveying, and stockpiling.

Dust emissions from dry percussion drilling operations can be controlled by adding water or water mixed with a surfactant into the air used for flushing the drill cuttings from the hole. Dilution ratios range from 800 to 3,000 parts of water to 1 part surfactant. An 89-mm diameter hole requires about 26 ℓ/hr of solution. This permits the drill cutting to be blown from the hole as damp, dust-free pellets (11).

In conventional mining of coal, water-filled plastic bags with or without solid stemming material (clay) are used for stemming dust emissions from blast holes. This method reduces dust concentrations by 20% to 80% and explosive consumption by about 10% (12). Instead of liquids, "thixotropic" cellulose or bentonite pastes can be used; gelatinous in repose, they liquefy when disturbed. Similar control methods may be applicable to the reduction of particulate emissions from blasting in granite mining.

---

(11) Jones, H. R. Fine Dust and Particulates Removal. Noyes Data Corporation, Park Ridge, New Jersey, 1972. 307 pp.

(12) Grossmueck, G. Dust Control in Open Pit Mining and Quarrying. Air Engineering, 10(25):21, 1968.

Release of carbon monoxide, nitrogen oxides, and other gases such as aldehydes and hydrogen can be curtailed by having a dry blast hole and by carrying out the detonation properly to prevent incomplete combustion.

Loading of the blasted granite into trucks by front end loaders results in dust emissions. Wetting of the broken stone with water or water mixed with a surfactant will alleviate the dust emissions. Emissions due to wind erosion during transport can be reduced by covering the load with a tarpaulin or by wetting its surface with water or water mixed with chemicals.

Water application is also an effective method for controlling emissions from unpaved roads; however, approximately 5% to 8% moisture (by weight) must be applied to suppress the dust emissions (13). Additives such as calcium chloride can be used to reduce the surface tension of water so that the dust can be wetted with less water. Calcium chloride can be applied at a cost of approximately $\$0.15/m^2$ treated/yr (14). The major problem involved in its use is its corrosion of vehicle bodies and leaching by rain water or melting snow.

Another effective method of dust control is to mix stabilizing chemicals into the road surface to a depth of approximately 20 mm to 50 mm (15). One cement company uses a special emulsion agent[a] and a treatment which involves spraying a solution of 4 parts of water and 1 part of the emulsion agent at the rate of $9.1\ \ell/m^3$ of the road surface. Certain pretreatment measures such as working the road surface into a stiff mud are necessary to prevent the binder in this emulsion agent from sticking to the vehicles. Periodic maintenance using a 1:7 emulsion agent/water solution spray keeps the emulsion agent binder active. This dust control program was found to give 3 yr of service at a total cost of $\$0.12/m^2$.

---

[a]Coheren, supplied by Golden Bears Division, Wetco Chemicals Company.

- - - - - - - - - - -

(13) Dust Suppression. Rock Products, 75:137, May 1972.

(14) Vandegrift, A. E., L. J. Shannon, P. G. Gorman, E. W. Lawless, E. E. Sallee, and M. Reichel. Particulate Pollutant Systems Study, Volume III: Handbook of Emission Properties. Contract CPA-22-69-104, U.S. Environmental Protection Agency, Durham, North Carolina, May 1971. 607 pp.

(15) Significant Operating Benefits Reported from Cement Quarry Dust Control Programs. Pit and Quarry, 63(7):116, 1971.

In some counties in Iowa, mixing cutback asphalt into the road surface to a depth of 50 mm to 80 mm has been investigated (16). This type of surface treatment reduces dust emissions, but it requires periodic maintenance such as patching of the potholes.

Treating the road surface with oil once a month is another efficient method of controlling unpaved road dust emissions. The cost for such applications is estimated to be $\$0.10/m^2$ treated/yr (11). However, a New Jersey study shows that 70% to 75% of the oil applied moves from the surface of the road to the surrounding ecosystem by dust transport and runoff. The oil or its heavy metal constituents such as lead may cause ecological harm (17). Furthermore, surface oiling requires regular maintenance because roads treated in this manner develop potholes.

Lignin sulfonates, byproducts from paper manufacture, are also used to control dust emissions. A commercially available lignin sulfonate[a] was tested on a farm access road at Arizona State University (18). The method proved quite successful, giving 5 yr of service and effective dust suppression at a cost of $\$0.47/m^2$ for 5 yr ($\$0.10/m^2$-yr).

Paving the road surface is the best method for controlling dusts, but it is impractical due to the high cost and the temporary nature of crushed granite plants.

The simplest and least expensive means of controlling dust from crushing, screening, conveying, and stockpiling is through the use of wetting agents and sprays at critical points.[b] A crushed rock production plant uses a dust suppression system[b] and a chemical wetting agent. Approximately 4 ℓ of the concentrated wetting agent is diluted 1,000 times by volume with water using an automatic proportioner. The solution is sprayed at the top and bottom of cone crushers at the rate of 4.2 ℓ of solution per metric ton of material being crushed. This system also helps reduce dust emissions at transfer points, screening operations,

---

[a] Orzan A, supplied by Crown Zellerbach Corporation.

[b] Chem-Jet, supplied by Johnson-March Corporation.

(16) Hoover, J. M. Surface Improvement and Dust Palliation of Unpaved Secondary Roads and Streets. ERI Project 856-S, Iowa State Highway Commission, Des Moines, Iowa, July 1973. 97 pp.

(17) Freestone, F. J. Runoff of Oils from Rural Roads Treated to Suppress Dust. EPA R2-72-054, U.S. Environmental Protection Agency, Cincinnati, Ohio, October 1972. 29 pp.

(18) Bub, R. E. Air Pollution Alleviation by Suppression of Road Dust. M.S.E. Thesis, Arizona State University, Tempe, Arizona, June 1968. 45 pp.

storage bins and stockpiling operations (19). Such a system has many cost-saving advantages. It requires no ducts, hooding or other enclosures for crushers, screens, or conveyors. The equipment is in the open and allows the operators to see the material flow. The dust is not collected, and there is no solid waste disposal or water pollution problem.

In a crushed stone plant (with processes similar to those of a crushed granite plant), a baghouse is used to control dust emissions from cone crushers, scalping and twin sizing screens, and shuttle and transfer conveyors.

The range of dust collected is 2,722 kg to 5,443 kg in a 10-hr day from a 182 metric ton/hr plant (20). A baghouse does not provide for dust control in stockpile areas unless these areas are totally enclosed. The dust collected in the baghouse presents a solid waste problem. The alternative disposal methods are to put the dust into settling basins or to develop sales opportunities. Depending on the type of material and the local market conditions, uses may include manufactured sand, underslab fill, and asphalt filler (21).

---

(19) Harger, H. L. Methods Used by Transit Mix Operators to Meet Air Pollution Control District Requirements. National Sand and Gravel Association and National Ready Mixed Concrete Association, Washington, D.C., April 1971. 22 pp.

(20) Trauffer, W. E. Maine's New Dust-Free Crushed Stone Plant. Pit and Quarry, 63(2):96, 1970.

(21) Ozol, M. A., S. R. Lockete, J. Gray, R. E. Jackson, and A. Preis. Study to Determine the Feasibility of an Experiment to Transfer Technology to the Crushed Stone Industry. Contract NSF-C826, National Science Foundation, June 1974. 50 pp.

SECTION 6

GROWTH AND NATURE OF THE INDUSTRY

PRESENT TECHNOLOGY

Present technological improvements include the use of larger and more efficient crushing and screening plants. Primary crushing is often done near the pit with jaw or gyratory crushers. Secondary crushing is done by cone crushers or gyratories. The crushed granite is screened and sent to open area storage. In larger and more efficient plants, granite is drawn out through tunnels under storage piles, and mixing equipment is used to blend any desired mixture of sizes.

EMERGING TECHNOLOGY

This study did not reveal emerging technology of specific importance to air pollution control in the crushed granite industry.

PRODUCTION TRENDS

Production of crushed granite is tied very closely to the granite-consuming industries. The production of crushed granite is associated chiefly with the needs of the construction industry (3), which was more than 94% of the crushed granite output. Production of crushed granite was 96.5 million metric tons in 1972. In 1973, a total of 109.4 million metric tons, and in 1974, 107.5 million metric tons of crushed granite were either shipped or used by producers in the United States (22). Assuming the same annual growth rate as that for the sand and gravel industry (3.9% to 4.7%), the contingency forecast of crushed granite demand in the year 2000 is 330 to 420 million metric tons.

Transportation constitutes a major part of the delivered cost of crushed granite. These costs may exceed the sales value of the material at the processing plants, even though crushed granite plants are located near the point of use. Local zoning and environmental regulations and depletion of urban deposits may necessitate the location of future crushed granite plants much farther

---

(22) Mineral Industry Surveys. Annual Advance Summary. U.S. Department of the Interior, Washington, D.C., September 17, 1975. 12 pp.

from the point of use and increase the use of rail and barge systems to hold down transportation costs. Truck haulage will remain important, especially for local delivery of crushed granite, despite the use of rail and water transportation for long distance to central distribution points. These factors will undoubtedly result in an increase in the delivered price of crushed granite.

REFERENCES

1. Clews, F. H. Heavy Clay Technology, Second Edition. Academic Press, New York, New York, 1969. pp. 1, 4.

2. 1972 Census of Mineral Industries, Subject Series: General Summary. MIC 72(1)-1, U.S. Department of Commerce, Washington, D.C., 1975. 174 pp.

3. Mineral Industry Surveys. U.S. Department of the Interior, Washington, D.C., 1972. 12 pp.

4. Sax, N. I. Dangerous Properties of Industrial Materials, Third Edition. Reinhold Book Corporation, New York, New York, 1968. pp. 1088-1089.

5. TLVs® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1976. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1976. p. 32.

6. Blackwood, T. R., P. K. Chalekode, and R. A. Wachter. Source Assessment: Crushed Stone. Contract 68-02-1874, U.S. Environmental Protection Agency, Cincinnati, Ohio, July 1977. 91 pp.

7. 1972 National Emissions Report. EPA-450/2-74-012, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974. 422 pp.

8. Turner, D. B. Workbook of Atmospheric Dispersion Estimates. Public Health Service Publication No. 999-AP-26, U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio, May 1970. 84 pp.

9. Nonhebel, G. Recommendations on Heights for New Industrial Chimneys. Journal of the Institute of Fuel, 33:479, 1960.

10. Blackwood, T. R., and R. A. Wachter. Source Assessment: Coal Storage Piles. Contract 68-02-1874, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, July 1977. 96 pp.

11. Jones, H. R. Fine Dust and Particulates Removal. Noyes Data Corporation, Park Ridge, New Jersey, 1972. 307 pp.

12. Grossmueck, G. Dust Control in Open Pit Mining and Quarrying. Air Engineering, 10(25):21, 1968.

13. Dust Suppression. Rock Products, 75:137, May 1972.

14. Vandegrift, A. E., L. J. Shannon, P. G. Gorman, E. W. Lawless, E. E. Sallee, and M. Reichel. Particulate Pollutant Systems Study, Volume III: Handbook of Emission Properties. Contract CPA-22-69-104, U.S. Environmental Protection Agency, Durham, North Carolina, May 1971. 607 pp.

15. Significant Operating Benefits Reported from Cement Quarry Dust Control Programs. Pit and Quarry, 63(7):116, 1971.

16. Hoover, J. M. Surface Improvement and Dust Palliation of Unpaved Secondary Roads and Streets. ERI Project 856-S, Iowa State Highway Commission, Des Moines, Iowa, July 1973. 97 pp.

17. Freestone, F. J. Runoff of Oils from Rural Roads Treated to Suppress Dust. EPA R2-72-054, U.S. Environmental Protection Agency, Cincinnati, Ohio, October 1972. 29 pp.

18. Bub, R. E. Air Pollution Alleviation by Suppression of Road Dust. M.S.E. Thesis, Arizona State University, Tempe, Arizona, June 1968. 45 pp.

19. Harger, H. L. Methods Used by Transit Mix Operators to Meet Air Pollution Control District Requirements. National Sand and Gravel Association and National Ready Mixed Concrete Association, Washington, D.C., April 1971. 22 pp.

20. Trauffer, W. E. Maine's New Dust-Free Crushed Stone Plant. Pit and Quarry, 63(2):96, 1970.

21. Ozol, M. A., S. R. Lockete, J. Gray, R. E. Jackson, and A. Preis. Study to Determine the Feasibility of an Experiment to Transfer Technology to the Crushed Stone Industry. Contract NSF-C826, National Science Foundation, June 1974. 50 pp.

22. Mineral Industry Surveys. Annual Advance Summary. U.S. Department of the Interior, Washington, D.C., September 17, 1975. 12 pp.

23. Chaiken, R. F., E. B. Cook, and T. C. Ruhe. Toxic Fumes from Explosives. Ammonium Nitrate-Fuel Oil Mixtures. Bureau of Mines RI-7867 (PB 233 496), U.S. Department of the Interior, Washington, D.C., May 1974. 29 pp.

24. Chalekode, P. K., and T. R. Blackwood. Source Assessment: Transport of Sand and Gravel. Contract 68-02-1874, U.S. Environmental Protection Agency, Cincinnati, Ohio. (Preliminary document submitted to the EPA by Monsanto Research Corporation, December 1974.) 87 pp.

25. Cheng, L. Formation of Airborne-Respirable Dust at Belt Conveyor Transfer Points. American Industrial Hygiene Association Journal, 34(12):540-546, 1973.

26. Cowherd, C. Development of Emission Factor for Fugitive Dust Sources. EPA-450/3-74-037, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974. 172 pp.

27. Blackwood, T. R., T. F. Boyle, T. L. Peltier, E. C. Eimutis, and D. L. Zanders. Fugitive Dust from Mining Operations. Contract 68-02-1320, Task 6, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1975. p. 34.

28. Andresen, W. V. Industrial Hygiene Design in Raw Materials Handling Systems. American Industrial Hygiene Association Journal, 23(6):509-513, 1962.

29. Lilienfeld, P., and J. Dulchinos. Portable Instantaneous Mass Monitor for Coal Mine Dust. American Industrial Hygiene Association Journal, 33(3):136, 1972.

30. Eimutis, E. C., and M. G. Konicek. Derivations of Continuous Functions of the Lateral and Vertical Atmospheric Dispersion Coefficients. Atmospheric Environment, 6(11):859-863, 1972.

31. Martin, D. O., and J. A. Tikvart. A General Atmospheric Diffusion Model for Estimating the Effects on Air Quality of One or More Sources. Presented at the 61st Annual Meeting of the Air Pollution Control Association, St. Paul, Minnesota, June 23-27, 1968. 18 pp.

APPENDIX A

LITERATURE SURVEY

A study was made to predict and analyze those parameters affecting dust emissions from the seven handling operations in crushed limestone processing:

- Drilling and blasting
- Transport
- Conveying
- Unloading
- Open storage
- Loading
- Crushing/grinding/sizing

There were two major classifications of parameters: those dependent on the material, and those dependent on the operation. Material-dependent parameters are generally the same for all operations. These are: moisture content, density, and "dustiness index," which will be defined as the mass of respirable dust adhering to 2.2 kg of material. Density, delineates differences in particle size distribution between different samples of the same material. The "dustiness index" is used to determine differences in emissions from different materials undergoing the same operation. Parameters dependent on the operation are as varied as the operations themselves.

DRILLING AND BLASTING OPERATIONS

The following factors influence the dust emissions from drilling operations:

- Number of bits
- Sharpness of the bits
- Speed of the bits
- Depth of bit penetration
- Experience of the machine operator

The literature search did not yield quantitative data indicating a relationship between the emission factor (E_D) and the aforementioned factors. A qualitative relationship might possibly resemble:

$$E_D \propto \frac{(1)(3)}{(2)(4)(5)} \qquad \text{(A-1)}$$

where the numbers in parentheses represent functions of the respective variables shown above.

Of all the unit operations, blasting as a cause of dust emissions has been studied least. The literature search yielded a potential list of factors influencing emissions; frequency of blasting, bulk moisture content of the rock, particle size distribution, type and amount of explosive, and hole size.

Studies have been conducted on the magniture of gaseous emissions of nitrogen oxides and carbon monoxide from blasting. Stoichiometric ratios of ammonium nitrate-fuel oil (ANFO) mixtures (5.5% fuel oil) should not produce nitrogen oxide and carbon monoxide emissions. Theoretically, a higher percentage of fuel oil should not give nitrogen oxides; it should yield more carbon monoxide and carbon dioxide. Conversely, a lower percentage of fuel oil should not produce carbon monoxide, and it should give more nitrogen oxides than nitrogen.

Experimental investigations by the Bureau of Mines (23) show that 4% fuel oil results in 1.3 m^3 (at standard conditions) of NO_x per kg of ANFO and 1.3 m^3 of CO per kg of AFNO, while 6% fuel oil results in 0.32 m^3 of NO_x per kg of ANFO and 1.8 m^3 of CO per kg of ANFO. The maximum emission factor figures have been used for the severity calculations.

TRANSPORT OPERATIONS

Transport operations are discussed in detail in another assessment document (24).

---

(23) Chaiken, R. F., E. B. Cook, and T. C. Ruhe. Toxic Fumes from Explosives. Ammonium Nitrate-Fuel Oil Mixtures. Bureau of Mines RI-7867 (PB 233 496), U.S. Department of the Interior, Washington, D.C., May 1974. 29 pp.

(24) Chalekode, P. K., and T. R. Blackwood. Source Assessment Transport of Sand and Gravel. Contract 68-02-1874, U.S. Environmental Protection Agency, Cincinnati, Ohio. (Preliminary document submitted to the EPA by Monsanto Research Corporation, December 1974.) 87 pp.

CONVEYING OPERATIONS

Dust emissions from conveying operations come from windblown dust during open conveying and conveyor discharge.

Emissions from conveyor discharge and parameters affecting these emissions have been evaluated (25). The material was freshly mined coal, cut during a dry operation and placed in plastic bags to maintain its natural surface moisture of about 0.8% as measured by a Soiltest Speedy Moisture Tester. The following relationship was found:

$$R = 8.50 \times 10^{5} \left(\frac{A\bar{\rho}_C \sqrt{2Gd}}{2MBU_B} \right)^{1.16} \qquad \text{(A-2)}$$

where R = specific formation of airborne respirable dust, g
A = cross-sectional area of the falling granules, cm^2
$\bar{\rho}_C$ = material density of the coal, g/cm^3
G = gravitational acceleration = 980 cm/s^2
d = height of fall, cm
M = belt load, g/cm^2
B = width of the conveyor belt, cm
U_B = linear speed of the conveyor belt, cm/s

The study lead to the following conclusions:

- About 10% of the adhering respirable dust becomes airborne by the impact of dropping.
- Reduction of the height of material fall reduces the formation of airborne respirable dust.
- For heavy belt loads (coal bed thickness >> mean lump size), an increase in the thickness of the coal bed reduces the specific formation of airborne respirable dust.

UNLOADING OPERATIONS

Emissions from unloading operations are produced by dropping materials from conveying machinery onto storage piles. A recent study (26) showed that the emission factors, E, for unloading

---

(25) Cheng, L. Formation of Airborne-Respirable Dust at Belt Conveyor Transfer Points. American Industrial Hygiene Association Journal, 34(12):540-546, 1973.

(26) Cowherd, C. Development of Emission Factor for Fugitive Dust Sources. EPA-450/3-74-037, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974. 172 pp.

operations, based on milligrams of suspended dust particles <30 μm in diameter per kilogram of aggregate unloaded, obeyed following relationship:

$$E = \frac{20 \text{ mg of particulate}}{\text{kg of aggregate}} \qquad \text{(A-3)}$$

This emission factor was based on high volume sampling at a sand and gravel plant in the Cincinnati area. E was dependent on the surface moisture of the material, estimated by the Precipitation-Evaporation (P-E) Index.

For an analysis of other factors affecting emissions from unloading operations, see Section 3, "Conveying Operations." Although the relationships derived for emissions from conveyor discharge are based on coal conveyance, only a correction factor for the relative dustiness of the material handled need be applied to make the equation applicable to all conveying and unloading operations.

OPEN STORAGE

Emissions due to open storage have been discussed to detail in previous documents (9,25,27).

LOADING OPERATIONS

Emissions from loading operations occur in the transfer of material from storage to transporting vehicles. For aggregates, this transfer is accomplished by power shovels or front-end loaders scooping the material from open storage piles and dumping it into transporting vehicles, usually trucks. Dust rises from the scooping and the dropping processes.

Emissions from dropping are determined by many of the same parameters that determine dust formation from conveyor discharge, although there are definite dissimilarities in mode of discharge between conveyor belts and power shovels. Dust emissions should be determined by:

1) Height of material fall
2) Quantity of material dumped
3) Density of material
4) Rate at which material is dumped

---

(27) Blackwood, T. R., T. F. Boyle, T. L. Peltier, E. C. Eimutis, and D. L. Zanders. Fugitive Dust from Mining Operations. Contract 68-02-1320, Task b, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1975. p. 34.

5) Moisture content of material

6) "Dustiness index" of material

An equation determining the amount of respirable dust, R, formed by power shovel discharge, based on an equation for conveyor discharge, should be of the form:

$$R \propto \frac{(1)(3)(6)}{(2)(4)(5)} \qquad \text{(A-4)}$$

where each number in parenthesis represents a function of its respective parameter as listed above.

Dust emissions from scooping operations are more difficult to define, because relevant information was not available. However, the following factors play a large part in determining emissions from this source:

7) Density of material

8) Moisture content of material

9) "Dustiness index" of material

10) Degree of storage pile disturbance rendered by the scooping machinery

Although there is no basis for determining a relationship between these variables and respirable dust formation, R, a qualitative relationship might possibly resemble:

$$R \propto \frac{(7)(9)(10)}{(8)} \qquad \text{(A-5)}$$

where each number in parenthesis represents a function of its respective parameter as shown above.

Although not applicable to the determination of R, it has been found (26) that the emission factor, E, which can be expressed as milligrams of dust <30 μm in diameter emitted per kilogram of material loaded, for loading crushed limestone at an asphalt plant is represented by:

$$E = \frac{25 \text{ mg of dust}}{\text{kg of material loaded}} \qquad \text{(A-6)}$$

E was believed to vary with the P-E Index of the area considered.

CRUSHING/GRINDING/SIZING OPERATIONS

Emissions from crushing, grinding, and sizing operations are the result of respirable dust formation during size reduction and crusher or screen discharge.

The factors affecting discharge emissions are the same as those for conveyor and power shovel discharge (see "Conveying Operations" and "Loading Operations" above).

Dust emissions from size reduction are judged to be influenced by:

- "Dustiness index" of material
- Moisture content of material
- Degree of particle-size reduction
- Rate of material flow through size reducer

A qualitative expression for respirable dust formation, R, is believed to be:

$$R \propto \frac{(1)(3)}{(2)(4)} \qquad \text{(A-7)}$$

where each number in parenthesis is some function of the respective parameter listed above.

An induced air flow must be present for atmospheric dispersion of the respirable dust. For most crushers, which operate at a relatively low speed, air flow is induced only during discharge. (See "Conveying Operations" above for a quantitative evaluation of air flow induced by discharge.)

High speed pulverizers create air flow during size reduction as well as discharge. Air flow induced by high speed size reduction may be inferred from the literature to be inversely proportional to the rate of material flow through the size reducer (28).

---

(28) Andresen, W. V. Industrial Hygiene design in Raw Materials Handling Systems. American Industrial Hygiene Association Journal, 23(6):509-513, 1962.

APPENDIX B

SAMPLING - DETAILS AND RESULTS

SAMPLING SITE DESCRIPTION

The purpose of the sampling is to obtain data on plant emissions from various unit operations for which no published data were available.

Two crushed granite plants were chosen whose operations are representative of the crushed granite industry. Further, these plants were located in areas with favorable meteorological conditions for sampling.

Plant A

At this site, the blasted rock is loaded into the primary crusher by a front-end loader or shell loader. The granite rock, processed through the primary crusher 2.13-m cone and secondary crusher 1.68-m cone, is fed by a conveyor to a screen tower where it falls into a bin. From the bin, the material is loaded into railroad cars or trucks. The material may then be delivered directly to customers, or it may be stockpiled. The crushed granite from the stockpile is loaded into trucks by a conveyor.

The plant operates on a continuous basis at 10 hr/day for 5 days/week. The average production rate of material processed through the primary crusher is 680 metric tons/hr; that through the secondary screening house is 430 metric tons/hr.

The major dust emission control method is the application of water to the haul roads from the quarry area to the plant. The quarry operations and the primary crushing take place in a pit and hence are only minor contributors to the overall plant emissions. The major contributor is the secondary crushing and screening unit. The sampling data and the results are given in Table B-1.

Plant B

At this site, the blasted material is loaded out with two 4.2-m^3 shovels into six 32-metric ton trucks to be hauled and dumped into a 107-cm x 122-cm jaw crusher. The material is then processed through two scalping screens and then through two 1.7-m

TABLE B-1. SAMPLING DATA AND RESULTS

Unit operation	Coordinates, m[a] x	y	z	Wind speed, mph	Sampling time, min	Concentration, $\mu g/m^3$	Emission rate, g/s	Total or respirable particulate[b]	Atmospheric stability class
					Plant A - Run 1				
Secondary crushing-screening	300	0	0	5.0	230	687.7	1.870	T	C
Secondary crushing-screening	310	120	0	5.0	230	759.[illegible]	2.641	T	C
Secondary crushing-screening	390	0	0	5.0	230	628.3	2.281	T	C
Secondary crushing-screening	320	100	0	5.0	230	1,154.8	3.890	T	C
Drilling, dry	78	20	0	3.0	4	1,540.0	3.562×10^{-1}	R[c]	C
Dump to first crusher	60	0	0	3.0	4	370.0	3.235×10^{-3}	R[d]	C
Dump to first crusher	60	0	0	3.0	4	260.0	2.273×10^{-3}	R	D
					Plant A - Run 2				
Secondary crushing-screening	288	83	0	6.7	235	949.6	2.153	T	D
Secondary crushing-screening	258	209	0	6.7	235	632.9	2.421	T	D
Secondary crushing-screening	375	108	0	6.7	235	775.6	2.482	T	D
Secondary crushing-screening	274	193	0	6.7	235	1,006.6	3.631	T	D
Blasting	2,300	0	230	7.0	45	763.4	1.908×10^{6}	T	D
					Plant B - Run 1				
Overall plant emission	540	0	0	4.0	235	424.2	1.009	T	D
Overall plant emission	570	120	0	4.0	235	525.6	1.609	T	D
Overall plant emission	660	0	0	4.0	235	323.2	9.573×10^{-1}	T	D
Overall plant emission	520	180	0	4.0	235	518.3	1.858	T	D
Secondary crushing	60	15	0	2.0	4	720.0	3.606×10^{-2}	T	B
Secondary crushing	60	15	0	2.0	4	1,190.0	5.959×10^{-2}	R[e]	B
Secondary crushing	60	15	0	2.0	4	1,320.0	6.610×10^{-2}	R	B
Secondary crushing	120	30	0	2.0	4	200.0	3.939×10^{-2}	R	B
Secondary crushing	120	30	0	2.0	4	150.0	2.954×10^{-2}	R	B
Secondary crushing	160	0	0	2.0	4	380.0	5.520×10^{-2}	R	B
Secondary crushing	60	0	0	2.0	4	2,330.0	5.650×10^{-2}	R	B
Secondary crushing	60	0	0	2.0	4	2,570.0	6.232×10^{-2}	R	B
Secondary crushing	160	40	0	2.0	4	140.0	4.888×10^{-2}	R	B
Drilling, wet	90	22	0	2.0	4	70.0	1.159×10^{-2}	T	D
Drilling	90	22	0	2.0	4	130.0	2.152×10^{-2}	T	D
Drilling	90	0	0	2.0	4	560.0	6.728×10^{-3}	T	D
Drilling	90	22	0	2.0	4	130.0	2.152×10^{-2}	T	D
Drilling	90	0	0	2.0	4	120.0	1.442×10^{-3}	R	D
Drilling	90	0	0	2.0	4	130.0	1.562×10^{-3}	R	D

[a] See Figure B-1. [b] T = total particulate; R = respirable particulate. [c] Two dumps. [d] One dump. [e] One truck passed.

cone crushers. From here, crushed granite is conveyed by a 152-m belt conveyor to a secondary plant.

At the secondary plant, 13 screens separate the aggregate sizes, and the crushed granite is then fed into one of two blending tunnels. From that blender, it is either trucked to customers or to storage, or loaded into railroad cars. The fine crushings are fed to two 2.1-m short-head crushers and transferred to a sand plant. The wet slurry from the screenings is fed to a sump that pumps it to a settling pond. About 90% of the pond water is reused in the process.

The plant operates on a continuous basis at 10 hr/day for 5 days/week. The average production rate through the primary crusher is 590 metric tons/hr, the same as the processing rate through the secondary crusher.

The major dust emission control method is the use of wet screening operations. However, unlike Plant A, vehicular traffic on the haul roads is a major contributor of overall plant emissions. The sampling data and the results are given in Table B-1.

SAMPLING PROCEDURES

Samplers

General Metal Works® high-volume (hi-vol) samplers were positioned around an area as shown in Figure B-1. For this arrangement, the origin was defined as the source, and all remaining points were in the usual Cartesian coordinate system. The angle of mean wind direction was θ. The downwind distance of any point y_i perpendicular to the wind direction centerline was computed in the following manner:

$$m_1 = \tan \theta$$

and for point S_i with coordinates x_i, y_i

$$m_2 = \frac{y_i}{x_i}$$

the angle α was found from

$$\alpha = \arctan \frac{m_1 - m_2}{1 + m_1 \cdot m_2}$$

the lateral distance, Y_i, is:

$$Y_i = (\sin \alpha) \sqrt{x_i^2 + y_i^2}$$

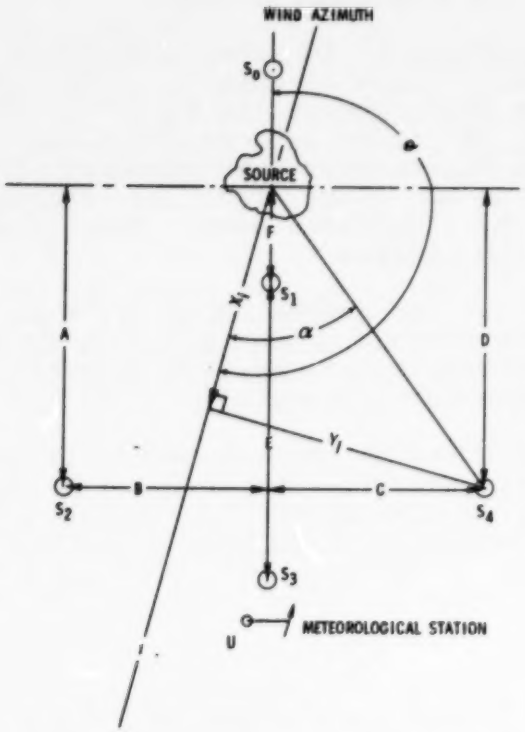

Figure B-1. Sampling arrangement.

and the downwind distance, X_i, is:

$$X_i = (\cos \alpha) \sqrt{x_i^2 + y_i^2}$$

These values are used in appropriate dispersion models. The sampling time for hi-vol samplers was about 4 hours. Five different hi-vol samplers were used to monitor the area emissions at positions S_0, S_1, S_2, S_3, and S_4.

A GCA[a] respirable dust monitor was used to obtain downwind concentrations of respirable and total particulates from unit operations (29). The sampling time for the GCA instrument was about 4 minutes, so only one unit was necessary to monitor at all the positions (not simultaneously).

---

[a]GCA Corporation, Technology Division, Redford, Massachusetts.

- - - - - - - - - -

(29) Lilienfeld, P., and J. Dulchinos. Portable Instantaneous Mass Monitor for Coal Mine Dust. Americal Industrial Hygiene Association Journal, 33(3):136, 1972.

The hi-vol samplers collect particles <100 μm in size, while the GCA unit collects <10-μm particles with a cyclone separator and <50-μm particles without a cyclone separator.

Models

Diffusion models, normally used to predict concentrations surrounding a point source of known strength, are used in reverse for open source sampling. Several concentration readings are taken to calculate the source strength of an open source.

Models applicable to the sampling arrangement and source characteristics are chosen and utilized for each emissive source. Two models are used in this study. The first represent emissions from secondary crushing and screening, dry drilling, dump to first crusher, overall plant emission, secondary crushing, wet drilling, and drilling.

This is the point source model (7) where:

$$\chi\ (x, y, z; H) = \frac{Q}{2\pi\sigma_y\sigma_z u}\ \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \cdot \cdot$$

$$\cdot \cdot \cdot \left\{ \exp\left[-\frac{1}{2}\left(\frac{z - H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z + H}{\sigma_z}\right)^2\right]\right\} \qquad \text{(B-1)}$$

The notation used to depict the concentration is χ (x, y, z; H). H, the height of the plume centerline from the ground level when it becomes essentially level, is the sum of the physical stack height, h, and the plume rise, ΔH. The following assumptions are made: the plume spread has a Guassian distribution in both the horizontal and vertical planes, with standard deviations of plume concentration distribution in the horizontal and vertical of σ_y and σ_z, respectively; the mean wind speed affecting the plume is u; the uniform emission rate of pollutants is Q; and total reflection of the plume takes place at the earth's surface, i.e., there is no deposition or reaction at the surface. Any consistent set of units may be used. The most common is χ in g/m^3, Q in g/s, u in m/s, and σ_y, σ_z, H, x, y, and z in meters. The concentration χ is a mean over the same time interval as the time interval for which the σ's and u are representative. The values of both σ_y and σ_z are evaluated in terms of the downwind distance, x, and stability class. Stability classes are determined conveniently by graphical methods as shown in Figure B-2 (26). Given the downwind distance, x (30), continuous functions are

(30) Eimutis, E. C., and M. G. Konicek. Derivations of Continuous Functions of the Lateral and Vertical Atmospheric Dispersion Coefficients. Atmospheric Environment, 6(11):859-863, 1972.

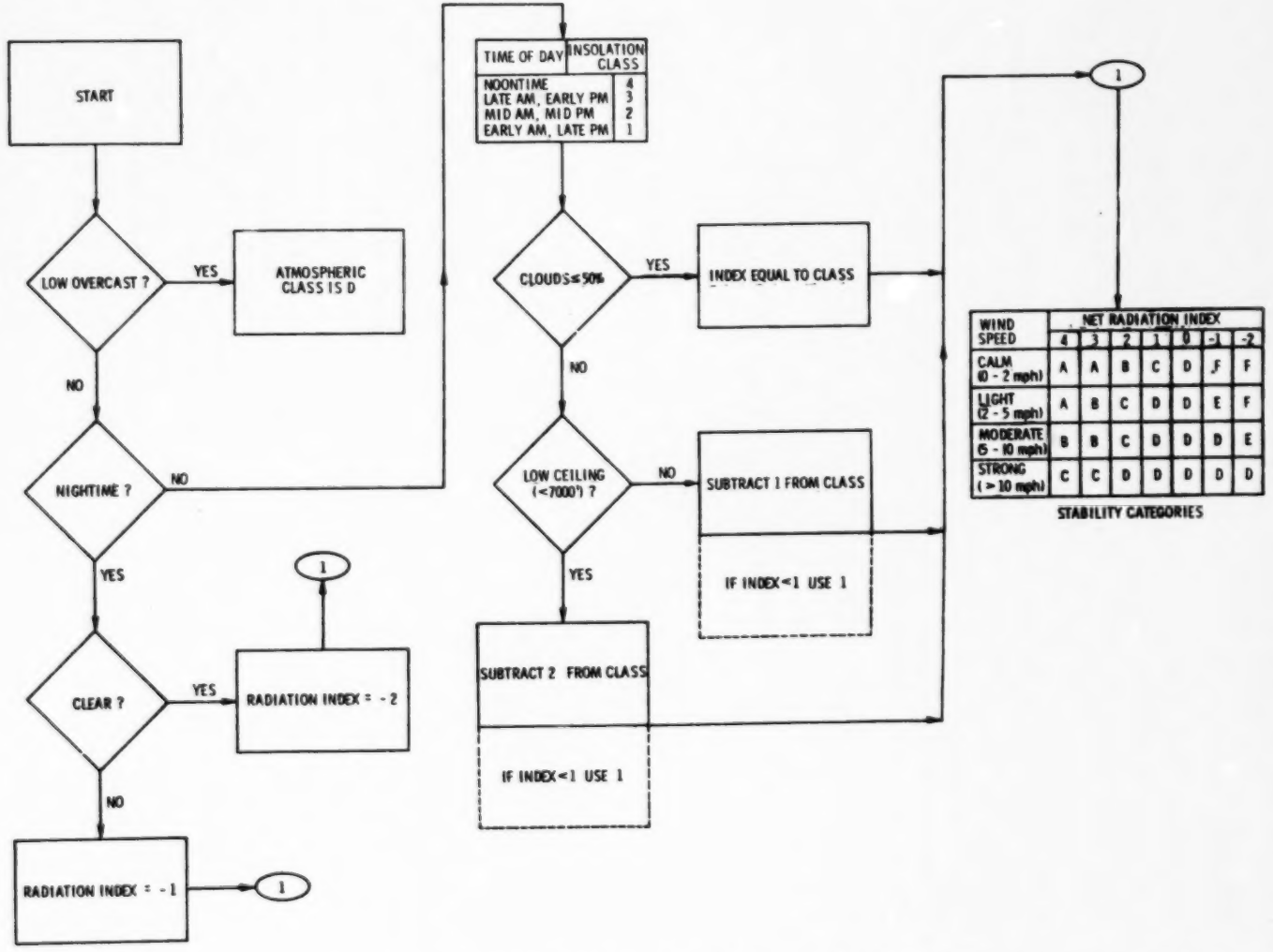

Figure B-2. Flow chart of atmospheric stability class determination (26).

then used to calculate values for σ_y, and σ_z, using the constants shown in Table B-2 and Table B-3 (31). In open source sampling, the sampler is maintained in the center of the plume at a constant distance; the plume has no effective height (H = 0); and the concentrations are calculated at ground level. Equation B-1 thus reduces to (7):

$$\chi\ (x,\ 0,\ 0;\ 0) = \frac{Q}{\pi \sigma_y \sigma_z u} \qquad \text{(B-2)}$$

The second model is used in computing total dose from a finite release in blasting. This is calculated from the dose model, Equation B-3 (7):

$$D_T = \frac{Q_T}{\pi \sigma_y \sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \qquad \text{(B-3)}$$

Q_T is the total release in grams from the source, and D_T is the total dose in g-s/m^3. Other parameters in Equation B-3 are the same units as Equation B-1. Again, the dose is the product of the concentration and sampling time.

Data Collection

Each variable for each of these models was determined in the field by high volume sampling at a nonportable meteorological station. Wind speeds were averaged every minute with a mean recorded for each 15-minute interval. The mean wind speed was calculated from the average of the 15-minute recordings over the entire run. The wind direction variation was less than ±45° from the centerline during the samplings. The samplers were therefore maintained within the plume during sampling.

The concentration at sampler S_0 was subtracted from the concentrations at S_1, S_2, S_3, and S_4 to yield those due to the source emissions. Mass emission rate was then calculated as an average of the calculations done for N sampler readings using the appropriate dispersion equation.

The respirable dust monitor was mounted on the portable meteorological station shown in Figure B-3. Each monitor concentration reading was displayed by direct digital readout. The wind meter, connected to the anemometer atop a 3.05-m pole, was read every 15 s. The mean wind speed was determined by averaging the 15-s

(31) Martin, D. O., and J. A. Tikvart. A General Atmospheric Diffusion Model for Estimating the Effects on Air Quality of One or More Sources. Presented at the 61st Annual Meeting of the Air Pollution Control Association, St. Paul, Minnesota, June 23-27, 1968. 18 pp.

TABLE B-2. CONTINUOUS FUNCTION FOR LATERAL ATMOSPHERIC DIFFUSION COEFFICIENT σ_y (30)

$$\sigma_y = Ax^{0.9031}$$

Stability class	A
A	0.3658
B	0.2751
C	0.2089
D	0.1471
E	0.1046
F	0.0722

TABLE B-3. CONTINUOUS FUNCTION FOR VERTICAL ATMOSPHERIC DIFFUSION COEFFICIENT σ_z (31)

$$\sigma_z = Ax^B + C$$

Usable range, m	Stability class	Coefficient		
		A_1	B_1	C_1
>1,000	A	0.00024	2.094	-9.6
	B	0.055	1.098	2.0
	C	0.113	0.911	0.0
	D	1.26	0.516	-13
	E	6.73	0.305	-34
	F	18.05	0.18	-48.6
		A_2	B_2	C_2
100 to 1,000	A	0.0015	1.941	9.27
	B	0.028	1.149	3.3
	C	0.113	0.911	0.0
	D	0.222	0.725	-1.7
	E	0.211	0.678	-1.3
	F	0.086	0.74	-0.35
		A_3	B_3	C_3
<100	A	0.192	0.936	0
	B	0.156	0.922	0
	C	0.116	0.905	0
	D	0.079	0.881	0
	E	0.063	0.871	0
	F	0.053	0.814	0

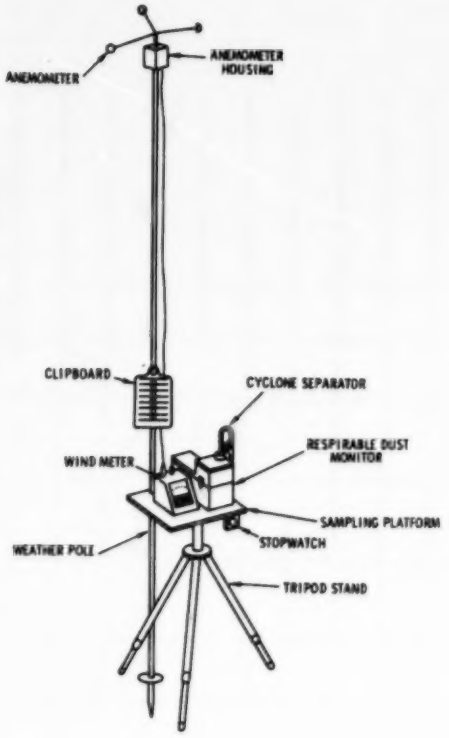

Figure B-3. Sampling apparatus.

readings. Distance x was approximated by pacing over the rough terrain. For each sampling run, all these data were recorded in the field on the form shown in Figure B-4. The time of day and atmospheric stability (determined according to the flow chart in Figure B-2) were recorded periodically on the bottom of the form.

The terms used on the field data form are explained in Table B-4.

Any factors that might have affected concentration or emission rate were mentioned in the column labeled "Comments." When this form was completed, the data were programmed into a computer and the emission rate, Q, calculated in accordance with the model specified in the column labeled "M."

EMISSION LEVELS

The parameters in Equation B-1 were measured in the field to obtain the emission rate (Q) per unit operation. These data were recorded on the form shown in Figure B-4 and printed out via computer. These values are shown in Table B-1, where the value of Q from the appropriate dispersion model was automatically computed. Using the site data presented earlier in this appendix, emission factors were computed as follows for each operation.

MODEL: POINT = 1
LINE = 2
DOSE = 3

SOURCE TYPE _____

DATE _____
BY _____

UNIT OPERATION	WIND SPEED, MPH	DISTANCE, FT. X	Y	Z	TIME, MIN.	READ., mg/m^3	CONC. μg/m^3	R/T	BGD, μg/m^3	Δ, μg/m^3	Q, g	S'	M	COMMENTS

TIME OF DAY ____ ____ ____ ____ ____
ATM. STABILITY ____ ____ ____ ____ ____

TOTAL SAMPLING TIME	MULTIPLY READING BY
4 MINUTES	1
8 MINUTES	0.46
16 MINUTES	0.23
20 MINUTES	0.184
30 MINUTES	0.122
37 MINUTES	0.1

Figure B-4. Field data form.

TABLE B-4. EXPLANATION OF FIELD DATA FORM TERMS

Term	Meaning
Read, mg/m^3	Concentration reading
Conc., $\mu g/m^3$	Converted concentration for sampling times greater than 4 min (lower right-hand corner)
R/T	Ratio of respirable to total particulate
BGD, $\mu g/m^3$	Background concentration
Δ, $\mu g/m^3$	The difference between the converted concentration and the background
Q, g or g/s	Calculated emission rate
S'	Stability for the time of day the unit operation was sampled
M	The model used referenced as 1, 2, or 3 (point, line, or dose, respectively)

Blasting

From the sampling data (Plant A, run 2), the emission rate of total particulates due to blasting is 1.9×10^6 g/blast. Assuming that one blast supplies the primary crusher with 3.5 days work (data from plant personnel) and knowing that Plant A has a production rate of 750 tons/hr operating for a 10-hr day, the amount of rock released by each blast is:

$$750 \frac{\text{tons}}{\text{hr}} \times 10 \frac{\text{hr}}{\text{day}} \times 3.5 \text{ days} = 26{,}250 \text{ tons}$$

The emission factor for total particulate due to blasting is thus:

$$EF = \frac{(1.9 \times 10^6 \text{ g})(10^{-3} \text{ kg/g})}{(26{,}250 \text{ tons})(0.9078 \text{ metric ton/ton})}$$

$$= 7.96 \times 10^{-2} \text{ kg total particulate/metric ton}$$

Sampling of crushed stone operations indicates that the ratio of respirable particulates to total particulate (R/T) is 0.169. Assuming the same ratio for crushed granite blasting, the emission factor is:

$EF = (7.96 \times 10^{-2})(0.169) = 1.35 \times 10^{-2}$ kg respirable particulate/ metric ton

Drilling

It is assumed that the representative plant uses wet drilling and that the total drilling time per blast is 176 hours. The emission rate for drilling is the average of the four wet drilling emission rates (Plant B, run 1) and is equal to 0.015 g total particulate/s. The emission factor is therefore:

$$EF = \frac{(0.015\ g/s)(176\ hr/blast)(3{,}600\ s/hr)(10^{-3}\ kg/g)}{(26{,}250\ tons/blast)(0.9078\ metric\ tons/ton)}$$

$$= 3.99 \times 10^{-4}\ kg\ total\ particulate/metric\ ton$$

Since the average of the two respirable emission rates is 1.5×10^{-3} g/s, the ratio of respirable particulates to total particulates (R/T) is thus 10%. The respirable particulate emission factor is:

$$EF = (3.99 \times 10^{-4}\ kg/metric\ ton)(0.10)$$

$$= 3.99 \times 10^{-5}\ kg\ respriable\ particulate/metric\ ton$$

Secondary Crushing and Screening

The average emission rate from secondary crushing and screening (Plang A, runs 1 and 2) is 2.67 g togal particulate/s. Using the production rate for Plant A, the emission factor is:

$$EF = (2.67\ g/s)(3{,}600\ s/hr)(hr/475\ tons)$$

$$(10^{-3}\ kg/g)(ton/0.9078\ metric\ ton)$$

$$= 2.2 \times 10^{-2}\ kg\ total\ particulate/metric\ ton$$

From the sampling data (Plant B, run 1), the R/T ratio can be calculated for secondary crushing. The average emission rate for secondary crushing is 4.84×10^{-2} g respirable particulate/s. The emission rate for total particulates as sampled by hi-vol samplers (determined from averaging the emission rates for overall plant emission) is 1.356 g total particulate/s. The R/T ratio for secondary crushing is thus:

$$\frac{4.84 \times 10^{-2}}{1.356} = 0.036$$

The respirable particulate emission factor from secondary crushing and screening is assumed to be 3.6% of the total particulate emission factor and is equal to 8.58×10^{-4} kg respirable particulate/metric ton.

Secondary Crushing Only--
From the sampling data (Plant B, run 1), the average emission rate of respirable particulates due to secondary crushing (excluding the run during which one truck passed the sampling area) is 4.84×10^{-2} g respirable particulate/s. Assuming R/T equals 0.039, the emission rate of total particulates is 1.24 g total particulate/s. Using the production rate for Plant B, the emission factor is:

$$EF = (1.24 \text{ g/s})(3{,}600 \text{ s/hr})(\text{hr}/650 \text{ tons})$$

$$(\text{ton}/0.9078 \text{ metric ton})(10^{-3} \text{ kg/g})$$

$$= 7.6 \times 10^{-3} \text{ kg total particulate/metric ton}$$

The plant used wet screening and, hence, there were no significant emissions from the screening operation.

Secondary Screening Only--
Since dry screening was used in Plant A, the emission factor is determined by subtracting the secondary crushing emission factor from the secondary crushing and screening emission factor.

$$EF = 2.2 \times 10^{-2} \text{ kg/metric tons} - 7.6 \times 10^{-3} \text{ kg/metric tons}$$

$$= 1.44 \times 10^{-2} \text{ kg total particulate/metric ton}$$

Dumping to Primary Crusher

The sampling data (Plant A, run 1) show two emission rates for respirable particulates during dumping to the primary crusher:

$$Q_1 = 3.235 \times 10^{-3} \text{ g/s for 2 dumps}$$

$$Q_2 = 2.273 \times 10^{-3} \text{ g/s for 1 dump}$$

Dividing Q in half to give the emission rate per dump and averaging Q_1 and Q_2 gives 1.68×10^{-3} g respirable particulate/s. Assuming that 25 trucks/hr dump at the primary crusher and that each truck has a capacity of 32 metric tons, the emission factor is:

$$EF = \frac{(1.68 \times 10^{-3} \text{ g/s})(3{,}600 \text{ s/hr})(\text{hr}/25 \text{ trucks})(\text{truck}/32 \text{ metric tons})}{10^3 \text{ g/kg}}$$

$$= 7.56 \times 10^{-6} \text{ kg respirable particulate/metric tons}$$

Emissions due to dumping at the primary crusher are assumed to be similar to emissions from secondary crushing; thus they have a R/T ratio of 0.036. The emission factor then for total particulates for dumping to the primary crusher is:

$$EF = 7.56 \times 10^{-6}/0.036 = 2.1 \times 10^{-4} \text{ kg total particulate/metric ton}$$

Vehicular Movement on Unpaved Roads

During a sampling run of secondary crushing operations (Plant B), one truck passed, creating an emission due to vehicular movement on an unpaved road. This emission rate may be determined from the secondary crushing data by averaging the emission rates (excluding the run during which the truck passed) and subtracting this average from the emission rate which includes that run. The difference is the vehicular movement emission rate:

6.61×10^{-2} g/s - 4.84×10^{-2} g/s = 1.77×10^{-2} g respirable particulate/s

The emission factor can be calculated by assuming that 8 trucks or loaders are in operation on dry unpaved roads for one hour and that the ratio of respirable particulate to total particulate (R/T) is comparable to the R/T ratio for vehicular movement on wetted roads in a crushed stone plant (0.176). The emission rate for total particulates is calculated as 1.01×10^{-1} g/s. The emission factor for total particulates is:

$$EF = \frac{(1.01 \times 10^{-1} \text{ g/s truck})(8 \text{ trucks})(3{,}600 \text{ s/hr})(10^{-3} \text{ kg/g})}{(650 \text{ tons/hr})(0.9078 \text{ metric tons/ton})}$$

$$= 4.91 \times 10^{-3} \text{ kg total particulate/metric ton}$$

Similarly, the respirable particulate emission factor is 8.64×10^{-4} kg/metric ton.

Total and respirable particulate emission factors for each source and the respective R/T ratio are tabulated in Table B-5. The overall emission factor for total particulates is 1.07×10^{-1} kg/metric ton. Similarly, the overall emission factor for respirable particulates is 1.53×10^{-2} kg/metric ton.

TABLE B-5. EMISSION FACTORS AND R/T RATIOS FOR PARTICULATE

Source	Total, kg/metric ton	R/T	Respirable, kg/metric ton
Blasting	7.96×10^{-2}	0.169	1.35×10^{-2}
Drilling	3.99×10^{-4}	0.10	3.99×10^{-5}
Secondary crushing and screening	2.2×10^{-2}	0.036	8.58×10^{-4}
Dumping to primary crusher	2.1×10^{-4}	0.036	7.56×10^{-6}
Vehicular movement on unpaved roads	4.91×10^{-3}	0.176	8.64×10^{-4}
TOTAL	1.07×10^{-1}	0.143	1.53×10^{-2}

COMPOSITION

The emissions from both plants were analyzed (6) for free silica, fibers, and trace elements. Fiber analysis of emissions from crushed granite operations is presented below.

Dust Samples from Granite Quarries

Table B-6 shows elemental analyses of dust samples from crushed granite quarries.

TABLE B-6. ELEMENTAL ANALYSIS OF DUST SAMPLE FROM GRANITE QUARRIES

	Weight percent				
	Plant A		Plant B		
Element	Run 1	Run 2	Run 1	Run 2	Plant A Blasting
Si	>10	>10	>10	>>10	>10
Fe	>10	>10	>10	>10	>10
Al	5-10	5-10	5-10	5-10	>10
Ca	5-10	5-10	5-10	5-10	>10
Na	4	4	4	3	4
Mg	0.7	2	3	5	1
Ti	1	1	1	0.8	3
Mn	0.2	0.3	0.2	0.5	0.2
Pb	0.02	N.D.[a]	N.D.	N.D.	N.D.
Ga	0.004	0.004	N.D.	N.D.	N.D.
Cr	0.002	0.002	N.D.	N.D.	N.D.
V	0.004	0.01	0.02	0.01	N.D.
Cu	0.004	0.002	0.08	N.D.	N.D.
Zr	N.D.	0.01	0.01	0.1	N.D.
Ag	N.D.	N.D.	N.D.	N.D.	0.04
Cl[b]	2-3	3-4	0.01	0.01	4-5
S[b]	4-5	3-4	5-6	∿10	∿11
K[b]	∿13	∿11	∿7	∿10	∿20

[a]Not detected.

[b]Semiquantitative estimates (±50%) by XRF. XRF measurements were performed directly on the filters. Emission spectrographic analyses were performed on loose particulates from the filters.

Free Silica Analysis from Crushed Granite Quarries

Table B-7 presents the results of free silica analysis of respirable emissions from crushed granite quarries.

TABLE B-7. FREE SILICA ANALYSIS FROM CRUSHED GRANITE QUARRIES TAKEN ON THE RESPIRABLE EMISSIONS

Sample source	Free silica, percent
Plant A	33.3
Plant A	30.1
Plant B	19.6

Mean value (Plants A and B): 27.7%
Standard deviation: 8.56%

Fiber Analysis of Emissions from Crushed Granite Operations

A fiber is a particle greater than 5 μm in length with a L/D of 3 or greater.

Field area = 0.005 mm^2

Count = 100 fields

Average count/field (Plant A, blasting) = 0.12

Ground level concentration (x = 701 m, y = 0, and z = 70 m from the source) = 0.03 fibers/mℓ

Emission factor for fibers = 3.13×10^9 fibers/metric ton

The mean source severity due to fiber emissions is 0.454 and the population affected by representative plant emissions with a severity of 0.1 is 227 persons, as calculated in Appendix C.

APPENDIX C

SOURCE SEVERITY AND AFFECTED POPULATION

TOTAL PARTICULATES

Source Severity

Maximum source severity for total particulates (6) is given as

$$S = \frac{4{,}020\ Q}{D^{1.814}} \qquad \text{(C-1)}$$

where S = maximum source severity
Q = emission rate, g/s
D = representative distance from the major source, (as defined in Section 4), m

The emission rate for total particulates from the representative plant is estimated as

$$Q = 454 \text{ metric tons/hr} \times 0.107 \text{ kg/metric ton} \times 1 \text{ hr}/3{,}600 \text{ s} \times 1{,}000 \text{ g/kg}$$

$$= 13.5 \text{ g/s}$$

Substituting the values of Q and D into Equation C-1, the severity for total particulates is

$$S = \frac{(4{,}020)(13.5)}{(410)^{1.814}} = 0.99$$

Affected Population

The affected population is defined as the population between plant boundaries and a maximum source severity (6) of 0.1.

$$x_S = \left(\frac{4{,}020\ Q}{S}\right)^{1/1.814} \qquad \text{(C-2)}$$

where x = distance from plant boundaries, m

$$x_{S=0.1} = \left[\frac{(4{,}020)(13.5)}{0.1}\right]^{1/1.814}$$

$$= 1{,}450 \text{ m}$$

$$x_{S=1.0} = \left[\frac{(4{,}020)(13.5)}{1.0}\right]^{1/1.814}$$

$$= 407 \text{ m}$$

Since the plant boundary is 410 m from the major source, the affected area is

$$A = \pi(1{,}450^2 - 410^2) = 6.1 \text{ km}^2 \qquad \text{(C-3)}$$

For a representative population density or 100 persons/km^2, the affected population is 610 persons.

FREE SILICA

Source Severity

Source severity for free silica emissions is given as (6)

$$S = \frac{316\ Q}{D^{1.814}\ TLV} \qquad \text{(C-4)}$$

where TLV is the threshold limit value for dusts containing free silica, which is given as

$$TLV = \frac{0.01}{\text{Percent free silica} + 2} \text{ g/m}^3 = 3.4 \times 10^{-4} \text{ g/m}^3$$

For free silica in the respirable particulates, the emission rate is 14.3% of the total particulate emission rate,

$$S = \frac{(316)(13.5)(0.143)}{(410)^{1.814}\ (3.4 \times 10^{-4}} = 32.7$$

Affected Population

$$x_S = \left[\frac{(316)(13.5)(0.143)}{(3.4 \times 10^{-4})S}\right]^{1/1.814}$$

For

$$S = 0.1,\ x_{S=0.1} = 10 \text{ km}$$

Since the distance of the plant boundaries is 0.41 km from the major source, the affected area is

$$\pi(10^2 - 0.41^2) = 314 \text{ km}^2$$

For a representative population density of 100 persons/km^2 the affected population is 31,400 persons.

NITROGEN OXIDES, CARBON MONOXIDE, AND FIBERS

The source severity for nitrogen oxides is calculated from Equation C-5 (6).

$$S_{NO_x} = \frac{22{,}200\ Q}{D^{1.90}} \qquad \text{(C-5)}$$

The emission rate for nitrogen oxides from the representative plant is estimated as

$$Q = 454 \text{ metric tons/hr} \times 2.85 \text{ g/metric ton} \times 1 \text{ hr}/3{,}600 \text{ s}$$

$$= 0.359 \text{ g/s}$$

The source severity is thus 0.089 at 410 m, and the affected population is zero. Severity for carbon monoxide is calculated from Equation C-6 (6).

$$S_{CO} = \frac{44.8\ Q}{D^{1.81}} \qquad \text{(C-6)}$$

The carbon monoxide severity is 1.7×10^{-4} at 410 m, and the affected population is zero.

Source severity for fibers is calculated from Equation C-4, as described earlier.

$$S_F = \frac{316\ Q}{TLV \cdot D^{1.814}} \qquad \text{(C-4)}$$

Using an emission factor of 3.13×10^9 fibers/metric ton for the 454 metric ton/hr representative plant, and using the TLV for asbestos fibers of 5 fibers/cm^3, the severity is thus 0.454.

The affected population is found by computing the affected area and multiplying by the representative population as follows:

$$x_S = \left[\frac{316\ Q}{(TLV)(S)}\right]^{1/1.814} \qquad \text{(C-7)}$$

For

$$S = 0.1, \quad x_S = 0.944 \text{ km}$$

Since the distance of the plant boundaries is 0.41 km from the major source, the affected area is

$$\pi(0.944^2 - 0.41^2) = 2.27 \text{ km}^2$$

For a representative population density of 100 persons/km^2, the population affected is 227 persons.

GLOSSARY

ANFO: Ammonium nitrate and fuel oil mixture used as an explosive.

azimuth: Horizontal direction expressed as the angular distance between the direction of a fixed point (as the observer's heading) and the direction of the object.

cone crusher: Vertical shaft crusher having a conical head.

confidence interval: Range over which the true mean of a population is expected to lie at a specific level of confidence.

criteria pollutant: Pollutant for which ambient air quality standards have been established.

dustiness index: Reference used in measuring the amount of dust settled where a material is dropped in an enclosed chamber; specifically, it is a measure of the mass of respirable dust adhering to 2.2 kg of material.

emission burden: Ratio of the total annual emissions of a pollutant from a specific source to the total annual state or national emissions of that pollutant.

fibrosis: Abnormal growth of fibrous connective tissue in an organ.

field area: Microscopic area examined for fiber content.

free silica: Crystalline silica defined as silicon dioxide (SiO_2) arranged in a fixed pattern (as opposed to an amorphous arrangement).

granite: Very hard igneous rock, usually gray or pink, consisting chiefly of crystalline quartz, feldspar, and mica.

gyratories: Crushers that move in a circular or spiral path.

hazard factor: Measure of the toxicity of prolonged exposure to a pollutant.

jaw crushers: Crushers that give a compression or squeeze action between two surfaces.

lignin sulfonates: Organic substances forming the essential part of woody fibers introduced into the sulfonic group by treatment with sulfuric acid.

limestone: Rock consisting mainly of calcium carbonate.

noncriteria pollutant: Pollutant for which ambient air quality standards have not been established.

precipitation-evaporation index: Reference used to compare the precipitation and temperature levels of various P-E regions of the United States.

processing plant: That portion of the quarry where the operation of crushing and size classification of stone occurs.

pulverizer: Crusher used to reduce stone size into powder or dust.

quarry: Term used to refer to the mining, processing plant, and material transfer operations.

representative source: Source that has the mean emission parameters.

respirable particulates: Those particles with a geometric mean diameter of ≤ 7 μm.

rock: Stone in a mass.

scalping screen: Screen used to prescreen the feed to crushers.

severity: Hazard potential of a representative source defined as the ratio of time-averaged maximum concentration to the hazard factor.

shortheads: Refers to a cone crusher.

shuttle conveyor: Conveyor used to move crushed stone back and forth between operations.

silicosis: Diffuse fibrosis of the lungs caused by the chronic inhalation of silica dust <10 μm in diameter.

sizing screen: Mesh used to separate stone into various sizes.

stone: Hard, solid, nonmetallic mineral matter of which rock is composed.

thixotropic: Relating to a property of gels to become liquid when shaken or disturbed.

threshold limit value: Concentration of an airborne contaminant to which workers may be exposed repeatedly, day after day, without adverse affect.